



Patent Application of
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for

**TITLE: LAMINATED LENS FOR INTRODUCING GAS-PHASE IONS INTO THE
VACUUM SYSTEMS OF MASS SPECTROMETERS**

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is entitled to the benefits of provisional Patent Applications Ser. Nr 60/410,653 filed September 13, 2002; provisional Patent Applications Ser. Nr 60/210,877 filed June 9, 2000 and Patent Application Ser. Nr. 09/877,167 filed June 8, 2001, now patent 6,744,041 issued 2004 June 1; and provisional Patent Applications Ser. Nr 60/384,869 filed June 1, 2002, now Patent Application Ser. Nr. 10/499,147 filed May 31, 2003.

FEDERALLY SPONSORED RESEARCH

The invention described herein was made with United States Government support under Grant Number: 1 R43 RR143396-1 from the Department of Health and Human Services. The U.S. Government may have certain ~~rights~~ rights to this invention.

SEQUENCE LISTING OR PROGRAM Not Applicable

~~BACKGROUND-FIELD OF INVENTION~~

BACKGROUND OF THE INVENTION--FIELD OF INVENTION

This invention relates to laminated lenses which are used for interfacing atmospheric pressure ionization sources to atmospheric inlets, such as apertures and glass capillaries, leading into mass spectrometers and ion mobility spectrometers.

~~BACKGROUND-DESCRIPTION OF PRIOR ART~~

BACKGROUND OF THE INVENTION

Dispersive sources of ions at or near atmospheric pressure; such as, atmospheric pressure discharge ionization, chemical ionization, photoionization, or matrix assisted desorption ionization, and electrospray ionization have low sampling efficiency through conductance or transmission apertures, where less than 1% [often less than 1 ion in 10,000] of the ion current emanating from the ion source make it into the lower pressure regions of the present interfaces for mass spectrometry. Thereafter, scientists have devised several means of delivering and transferring gas-phase ions from atmospheric pressure sources into the vacuum system of mass spectrometers, such as, using lower flow sprayers to form very small droplets [referred to as nanospray], using increased heating of the aerosols to generate more ions [such as the commercial product, TurboSpray by PE-Sciex], increasing the sampling diameter of the sampling aperture at the atmospheric-lower pressure interface, and using electrostatic, electrodynamic, or aerodynamic lens at atmospheric pressure to focus highly charged liquid jets, aerosols of droplets and ion clusters, and gas-phase ions.

Larger Entrance Aperture and Inlet Aperture Shape

Bruins (1991) summarizes several means for transferring ions from an atmospheric ion source into the vacuum system of a mass spectrometer: shape of lens and orifice size. Inlet apertures in a flat disk and in the tip of a cone pointed toward the ion source are presently the preferred means of ion sampling through various aperture configurations. By increasing the diameter of the inlet aperture

1 aperture, more ions are drawn into the aperture—the increase being related to the
2 increase in gas conductance. However, by increasing the conductance aperture
3 diameter, larger pumps are required to maintain the pressure in the lower pressure
4 regions, thereby, increasing the system and operating costs of mass spectrometers.
5 This is also the case for ion mobility spectrometers when operated at reduced
6 pressure.

7 U.S. patent 6,455,846 B1 to Prior et al. (2002) discloses a flared or horn inlet for
8 introducing ions from an atmospheric ionization chamber into the vacuum chamber
9 of a mass spectrometer. They also reported that the increase in ion current
10 recorded in the mass spectrometer was directly proportional to the increase in the
11 opening of the flared inlet.

12 **Electrical and Aerodynamic Lens**

13 Ion movement at higher pressures is not governed by the ion-optical laws used to
14 describe the movement of ions at lower pressures. At lower pressures, the mass of
15 the ions and the influence of inertia on their movement play a prominent role. While
16 at higher pressures the migration of ions in an electrical field is constantly impeded
17 by collisions with the gas molecules. In essence at atmospheric pressure there is
18 are so many collisions collisions, that the ions have no “memory” of previous
19 collisions and the initial energy of the ion is “forgotten”. Their movement is therefore
20 determined by the direction of the electrical field lines and the viscous flow of gases.
21 At low viscous gas flow, the ions follow the electric field lines [the situation at the
22 entrance to apertures and capillaries], while at higher viscous gas flow the
23 movement is in the direction of the gas flow. Inventors [as discussed below] have
24 disclosed various means of moving ions at atmospheric pressure by shaping the
25 electric field lines and directing the flow of gases.

26 **Housing Lens**

27 Inventors have proposed shaping the electrostatic field lines in front of the inlet
28 aperture using electrodes at a substantial distance from both the sprayer and the
29 inlet aperture. U.S patent 5,432,343 to Gulcicek et al. (1995) discloses a cylindrical
30 electrostatic lens in the atmospheric ionization chamber at an electrostatic potential
31 greater than the sprayer, the inlet aperture, and the end of a glass capillary coated

1 with a metal surface that shapes the electrostatic field lines within the ionization or
2 evaporation chamber. U.S. patents 5,559,326 to Goodley et al (1996) and
3 5,750,988 to Apffel et al. (1998) both disclose a needle electrode in front of the inlet
4 aperture and an electrified housing surrounding the sprayer. All of this work was for
5 the purpose of shaping the electrostatic field lines in front of the sampling aperture to
6 be either perpendicular to or converging onto the inlet aperture, however, these
7 configurations require the position of the sprayer or needle relative to the sampling
8 aperture to be set and predetermined so as to obtain maximum ion sampling.
9 Forcing the operator of the instrument to place the sprayer back in the original
10 position or to reoptimize the potentials to return to the original operating conditions.

11 **Atmospheric Pressure: Lens at Sprayer**

12 Several types of ring or planar electrodes at the sprayer have been proposed to
13 focus ions and charged droplets after they leave the sprayer. U.S. patent 4,531,056
14 to Labowsky et al. (1985) discloses a perforated diaphragm used to direct the flow of
15 a gas at an electrospray needle to aid the evaporation of highly charged droplets
16 emanating from the needle and sweep away gas-phase solvent molecules from the
17 area in front of the inlet aperture. In addition, the diaphragm was used to stabilize
18 the position of the needle to direct the liquid jet through a center aperture in the
19 diaphragm into a desolvation or ionization region.

20 Schneider et al. (2001, 2002) discloses a ring shaped electrode incorporated near
21 the tip of the electrospray needle which increased the detected ion signal and the
22 stability of the signal and at the same time decreasing the dependence of the ion
23 signal on the sprayer position.

24 **Low Pressure: Lens at Sprayer**

25 Similar types of electrodes have been disclosed to increase the ion signal of gas,
26 electrospray sources operated at lower pressures—for example, in U.S. patent
27 4,318,028 to Perel et al. (1982), Mahoney et al. (1987, 1990), and Lee et al. (1988,
28 1989). Our own patents U.S. patents 5,838,002 (1998) and 6,278,111 B1 (2001),
29 and World patent 98/07505 (1998) describes a concentric tube which surrounds the
30 end of the electrospray capillary which was used to stabilize the direction of the
31 liquid jet in order to direct the liquid jet into a heated high pressure region where the

1 jet broke up into small droplets and where gas-phase ions and ion clusters were
2 formed. This approach proved feasible but it was found to difficult to control the
3 collection and focusing of ions formed in this higher-pressure region due to the
4 electrical breakdown of the gases.

5 **Atmospheric Pressure Lens: Between Sprayer & Aperture; or at Aperture**

6 Several types of ring or planar electrodes positioned between the sprayer and an
7 inlet aperture have been proposed to focus ions and charged droplets: U.S. patents
8 4,300,044 to Iribane et al. (1981) and 5,412,208 to Covey et al. (1995) are examples
9 of placing an electrified lens immediately in front of the inlet aperture; U.S. patent
10 4,542,293 to Fenn et al. (1985) and U.S patent application 2003/0,038,236 to Russ
11 et al. (2003) disclose diaphragm and planar electrodes in front of a heated capillary
12 inlet; and U.S. patent 5,747,799 to Franzen (1998) discloses a ring electrode on the
13 inside wall of a heated capillary inlet in conjunction with the shape of the aperture to
14 entrain ions into the aperture by viscous friction. Olivares et al. (1987, 1988)
15 discloses a focusing ring located downstream of the electrospray sprayer, and U.S.
16 patent 5,306,910 to Jarrell et al. (1994) discloses a grid which is operated with an
17 oscillating electrical potential to form gas-phase ions from highly charge droplets,
18 while allowing the electrospray needle and entrance aperture to remain at ground
19 potential; however, most of the droplets impact impacted on the grid as they pass
20 through the grid, not making it into the inlet aperture. Feng et al. (2002) describes a
21 series of annular electrodes downstream of an induction electrode used to guide
22 charged droplets, and Alousi et al. (2002) describes a lens between the electrospray
23 needle and the entrance aperture dividing the ion source into two discrete areas—an
24 area for the creation of highly charged droplets and gas-phase ions and a drift region
25 leading to an increase of 2-10 fold in the signal intensity; however, most of the ion
26 current from the sprayer was deposited on the lens.

27 World patent 03/010794 A2 to Forssmann et al. (2003) discloses a series of
28 annular electrodes for ion acceleration and then subsequent ion focusing in front of
29 the inlet aperture, similar to the device described by Jarrell et al. (1994). Jarrell et
30 al.'s device utilize an oscillatory potential while Forssmann et al.'s device utilizes a
31 direct current potential to first accelerate charged drops away from the electrospray
32 needle, through an aperture in an accelerating electrode [or through an accelerating

1 grid in Jarrell et al.'s device], and then into a focusing region. In both cases, droplets
2 are accelerated away from an electrospray needle and travel up a potential gradient
3 into a focusing region due their momentum. Droplets and any gas-phase ions
4 resulting from the breakup of the droplets would more than likely impact on the
5 accelerating electrodes due to the diverging electrostatic fields along the axis of the
6 electrodes.

7 Our U.S. patent applications ~~09/877,167 (2001)~~ 6,744,041 (2004), and patent
8 application 10/499,147 (2003) describe perforated high transmission surfaces [both
9 single layer and laminated] with large electrostatic potential differences across the
10 structure [typically >10/1] for transferring ions from dispersive atmospheric ionization
11 sources into a focusing region where the ions can be focused into a small cross-
12 sectional ion beam for introduction into an inlet aperture. Nevertheless all the
13 atmospheric lens, electrodes, grids, and perforated structures heretofore known
14 suffer from a number of disadvantages:

15 (a) By using larger inlet apertures to increase the flow of ions into the vacuum
16 system, and the necessary vacuum pumping system to maintain low pressures
17 required for operation of the mass spectrometer, the initial and operating cost of the
18 instrument is expensive.

19 (b) The lens and electrodes between the ion source and the inlet aperture in
20 present use, with small electrical potential differences across the structure, are very
21 inefficient in transferring ions from one region to another, leading to a small
22 percentage [$<1\%$] of the ion current from the ion source making it into the inlet
23 aperture and the majority of the ion current impacting on the lens and the inlet
24 aperture.

25 (c) Surfaces, single layer and laminated, with large electrostatic potential
26 differences across the surface are very efficient at collecting and focusing dispersive
27 highly charged aerosols into beams with small cross-sections but the diverging fields
28 encountered at inlet apertures, due to large electrostatic difference between the
29 surfaces and the inlet, can lead to the lose of ions.

30 (d) By operating high electrostatic field ion sources or spray chambers, such as
31 electrospray and discharge sources, with cylindrical electrodes and needles, distal to

1 the inlet aperture, the potentials of the lens required to focus the ions is larger than
2 the potential of the ion source thereby operating the electrodes at potentials close to
3 their discharge limit. In addition, the position of the sprayers or nebulizers is pre-set
4 requiring re-optimization of the potentials every time the sprayer's original position is
5 change.

6 (e) By the positioning lenses or diaphragms immediately in front of or behind the
7 inlet aperture, most of the ion current from the sprayers ends up on the lens itself or
8 on the entrance of the inlet aperture because these lens lenses cannot overcome
9 the dispersive electrical potentials of the sprayers or nebulizers.

10 (f) By positioning a single lens or perforated electrode between the ion source
11 and the inlet aperture there is no way to dynamically shape or readjust the
12 electrostatic filed lines in the focusing region between the lens and the inlet aperture.

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19 **SUMMARY**

20 ~~In accordance with the present invention a laminated lens comprises alternate~~
21 ~~layers of conducting electrodes and insulating bases with upstream or entrance~~
22 ~~aperture of the lens being larger than the exit aperture, with an optional high~~
23 ~~transmission surface upstream of the laminated lens for the introduction of gas-~~
24 ~~phase ions or charged particles at or near atmospheric pressure into a mass~~
25 ~~spectrometer or ion mobility spectrometer. The voltages applied to elements are~~
26 ~~intended to provide a funnel shaped potential surface of user definable initial and~~
27 ~~exit potential relative to other components in the ion source.~~

1 **~~OBJECTS AND ADVANTAGES~~**

2 **BACKGROUND OF INVENTION--OBJECTS AND ADVANTAGES**

3 Accordingly, besides the objects and advantages of the laminated and single layer
4 high transmission surfaces described in our co-pending and issued patents, several
5 objects and advantages of the present invention are:

6 (a) to provide a laminated lens that can be easily incorporated into various
7 atmospheric ion sources in order to shape the electrostatic fields lines in front of an
8 inlet aperture for the purpose of focusing ions into the inlet aperture of an
9 atmospheric interface for a mass spectrometer;

10 (b) to provide a laminated lens and a high transmission surface that will establish
11 a focusing region of converging electrostatic fields in front of an inlet aperture that is
12 not dominated by the electrostatic fields emanating from the ion source region but by
13 the laminated lens and inlet aperture;

14 (c) to provide a laminated lens to focus a substantial proportion of ions from the
15 ion source into the inlet aperture and into the vacuum system of a mass
16 spectrometer without the need to enlarge the inlet aperture to get more ions into the
17 vacuum system;

18 (d) to provide dynamic focusing or shaping of the electrostatic field lines between
19 high transmission surface and the inlet aperture which can focus a substantial
20 proportion of the ions into the inlet aperture,

21 (e) to provide a to the operator a user controllable or tunable field ration across
22 single or ~~lamine~~ laminated high transmission elements that results in improved
23 transmission efficiency across thigh transmission elements into funnel-well regions,

24 (f) to a wider acceptance cross-section when sampling large volume sources
25 that are being collected into the laminated lens,

26 (g) to provide improved compression in funnel-well optical systems as described
27 in our issued patent 6,744,041 (June 1, 2004), and our co-pending patent
28 Applications Ser. Nr. 60/384,869 filed 2002 June 1, now Patent Application Ser. Nr.
29 10/499,147 filed 2003 May 31; and Ser. Nr. 60/384,864 filed 2002 June 1, now Ser.
30 Nr. 10/449,344, filed 2003 May 30.

1 (h) to reduce the well depth requirement for funnel-well optical devices which
2 create problems with high voltage safety and isolation.

3 Further objectives and advantages are to provide a lens which can be easily and
4 conveniently incorporated into existing atmospheric interfaces without the need for
5 extensive or major reconstruction of the interface, which is simple to operate and
6 inexpensive to manufacture, which can be used with highly dispersive or low
7 electrostatic or electrodynamic field ion sources, and which obviates the need to
8 have the sprayer's and or lens' placement or orientation preset. Still further objects
9 and advantages will become apparent from a consideration of the ensuing
10 descriptions and drawings.

11 **SUMMARY**

12 In accordance with the present invention a laminated lens comprises alternate
13 layers of conducting electrodes and insulating bases with upstream or entrance
14 aperture of the lens being larger than the exit aperture, with an optional high
15 transmission surface upstream of the laminated lens for the introduction of gas-
16 phase ions or charged particles at or near atmospheric pressure into atmospheric
17 inlets, such as apertures and capillaries, to mass or ion mobility spectrometers. The
18 voltages applied to conducting electrodes and high transmission surface are
19 intended to provide a funnel-shaped potential surface of user definable initial and
20 exit potentials relative to the source of ions and inlet into atmospheric inlets.

21 **DRAWING FIGURES**

22 ~~In the drawings, closely related figures have the same number but different~~
23 ~~alphabetic suffixes.~~

24 Figs 1A and 1B shows a cross-sectional illustration of a laminated lens for
25 introducing charged particles into the aperture of a (1A) planar lens, and (1B) a glass
26 tube coated with a metal coating.

27 Fig 2 shows a similar lens configured with a laminated high-transmission element
28 (Lam-HTE).

29 Fig 3 shows a similar lens configured with a laminated high-transmission element

1 (Lam-HTE) and an atmospheric pressure ionization source.

2 Fig 4 shows the laminated high-transmission element (Lam-HTE) with slotted
3 aperture openings: showing outer-laminated surface (4A) and inner-laminated
4 surface (4B).

5 Fig 5 shows a lens as a cross-sectional illustration of the ion source region and
6 laminated high-transmission element (Lam-HTE) with the cylindrical lens as two
7 separate elements.

8 Fig 6 shows a similar lens, ion source region, and a laminated high-transmission
9 element (Lam-HTE), with the outer laminate as two separate surfaces.

10 Figs 7A to 7C show additional means of focusing ions into the ion-funnel region
11 (7A) the inner-laminate of the laminated high-transmission element (Lam-HTE)
12 fabricated with additional electrodes; (7B) the cylindrical funnel wall electrically
13 isolated from the laminated-lens and laminated high-transmission element (Lam-
14 HTE); and (7C) a ring electrode.

15 Fig 8 shows a cone-shaped laminated lens adjacent to a laminated planar-shaped
16 high-transmission element.

17 Fig 9 shows a hemispherical-shaped laminated-lens adjacent to a planar shaped
18 high-transmission element (Lam-HTE).

19 Fig 10 shows a similar lens adjacent to a hemispheric-shaped laminated high-
20 transmission element (Lam-HTE).

21 Fig 11 shows planar-shaped lens without an adjacent laminated high-transmission
22 element (Lam-HTE), down stream of an atmospheric matrix assisted laser
23 desorption ionization (AP-MALDI) source.

1 REFERENCE NUMERALS IN DRAWINGS

2 10	metal laminate or layers	27 172	ring insulator
3 20	base	28 200	concurrent gas source
4 30	laminate/base inner surface	29 202	concurrent gas inlet
5 40	largest aperture	30 204	countercurrent gas source
6 50	smallest aperture	31 206	countercurrent gas inlet
7 60	aperture	32 208	exhaust destination
8 70	element	33 210	exhaust outlet
9 80	ion-collection region	34 300	laminated high transmission
10 90	deep-well focusing region	35	element
11 92	deep-well ring insulator	36 <u>300 Lam-HTE</u>	
12 94	metal laminate	37 310	inner-electrode surface
13 100	source	38 320	outer-electrode surface
14 110	delivery means	39 322	metal circular laminate
15 120	ion-source	40 330	second insulating base
16 124	laser	41 340	particle-stop
17 126	sample target	42 344	circular metal laminate
18 130	ion-source entrance wall	43 350	funnel-focusing electrode
19 140	ion-source cylindrical wall	44 352	circular electrode
20 142	cylindrical electrode	45 360	laminated openings
21 144	shielding electrode	46 400	funnel-focusing region
22 150	ring insulator	47 401	metal laminate
23 152	ring insulator	48 410	cylindrical funnel wall
24 160	ion-source region	49 412	ring insulator
25 162	generalized ion trajectories	50 414	ring insulator
26 170	second ring insulator	51 <u>414</u>	<u>second ring insulator</u>

52 ~~DESCRIPTION--FIGS 1 THRU 4--PREFERRED EMBODIMENT~~

53 DETAILED DESCRIPTION--FIGS 1 THRU--PREFERRED EMBODIMENT

54 A preferred embodiment of the laminated-lens, funnel lens or just lens of the
55 present invention is illustrated in Figs. 1A, 1B, and 2. The lens is made-up of a

1 series of thin concentric circular planar metal laminates or layers **10** separated from
2 each other by a thin circular base **20** of uniform cross section consisting of
3 nonconducting insulating material, each metal laminate/base pair having an
4 aperture, defined by a laminate/base inner surface **30**. In this series of metal
5 laminates and insulating bases, each adjacent aperture has a smaller diameter than
6 the previous aperture, the collection of the apertures thus forming a funnel shaped
7 lens. The lens thus has an entry, corresponding with the largest aperture **40**, and an
8 exit, corresponding with the smallest aperture **50** for introducing gas-phase ions or
9 charged particles into a deep-well region **90** where they are accelerated toward an
10 aperture **60** in the wall of an element **70**. The ions are transferred to an ion-
11 collection region **80** through aperture **60**. Element **70** is isolated from the metal
12 laminate **94** of the funnel lens by a deep-well ring insulator **92**. The deep-well
13 focusing region **90** is bounded by metal laminate **94**, element **70**, and deep-well ring
14 insulator **92**.

15 Aperture **60** has a diameter appropriate to restrict the flow of gas into region **80**. In
16 the case of vacuum detection, such as mass spectrometry in region **80**, typical
17 aperture diameters are 100 to 1000 micrometers. The collection region **80** in this
18 embodiment is intended to be the vacuum system of a mass spectrometer (interface
19 stages, optics, analyzer, detector) or other low-pressure ion and particle detectors.

20 In the preferred embodiment, the base **20** is glass. However the base can consist
21 of any other material that can serve as a nonconductive insulator, such as nylon,
22 Vespel, ceramic, various impregnated or laminated fibrous materials, etc.
23 Alternatively, the base can consist of other nonconductive or dielectric material, such
24 as ferrite, ceramics, etc. The metal laminates **10** are fabricated from a conducting
25 and chemically inert material, such as stainless steel, brass, copper, aluminum, etc.
26 While element **70** can also be made of a conducting material, such as stainless
27 steel, aluminum, etc, or a conductively coated insulating material, such as the glass
28 tube.

29 Upstream of the lens is a funnel focusing region **400**, a laminated high
30 transmission element **300**, and an ion-source region **160** of gas-phase ions or
31 charged particles formed at or near atmospheric pressure. Sample from a source
32 **100** is delivered to an ion-source **120** by a delivery means **110** through an ion-

1 source entrance wall **130**. Wall **130** is electrically isolated from an ion-source
2 cylindrical wall **140** by a ring insulator **150** while a second ring insulator **170** isolates
3 cylindrical wall **140** from a laminated high-transmission element **300**. Sample from
4 source **100** are gas-phase ions or charged particles or, alternatively, are neutral
5 species ~~which~~ which are ionized in the ion-source **120**. Ion-source region **120** is
6 bounded by the wall **130**, the cylindrical wall **140**, and the laminated high-
7 transmission element or Lam-HTE **300**.

8 The high-transmission element (Lam-HTE) **300** consist of a second insulating
9 base **330** laminated with an inner-electrode **310** and an outer-electrode **320** metal
10 laminate. The surface of the laminated high transmission element (Lam-HTE) has
11 slotted shaped laminated openings **360** through which gas-phase ions are
12 transmitted from the ion-source region **120** to the funnel-focusing region **400**.
13 Funnel-focusing region **400** is bounded by a cylindrical funnel wall **410**, the inner-
14 electrode surface **310** of the laminated high-transmission element (Lam-HTE) **300**,
15 and metal laminate **401** establishing the largest aperture **40** of the laminated lens.
16 On the surface of the outer laminate **320** is a raised particle-stop **340**, which is axial
17 symmetric with apertures **40**, **50**, **60**.

18 In the preferred embodiment, the second base **320** is also glass. However the
19 base can consist of any other material that can serve as an electrical insulator, such
20 as nylon, Vespel, ceramic, various impregnated or laminated fibrous materials, etc.
21 The metal laminates **310**, **320** are fabricated from a conducting and chemically inert
22 material, such as stainless steel, brass, copper, aluminum, etc. Alternatively, the
23 laminated element (Lam-HTE) **300** may be manufactured by using the techniques of
24 microelectronics fabrication: photolithography for creating patterns, etching for
25 removing material, and deposition for coating.

26 A DC (direct current) potential is applied to each metal laminate, electrode, and
27 element creating an electrical field, although a single power supply in conjunction
28 with a resistor chain can also be used, to supply the desired and sufficient potential
29 to each laminate, electrode, and element to create the desired net motion of ions, as
30 shown by generalized ion trajectories **162**, from the ion source region **160** through
31 the laminated openings of the high-transmission element (Lam-HTE) **300** into the
32 funnel-focusing region **400**, down the lens and exiting out through aperture **50**,

1 through the deep-well focusing region **90**, through the aperture **60**, and into the ion-
2 collection region **80**. Alternatively, in the case where the base **20** of the lens is
3 ~~composed~~ comprised of dielectric material a single power supply can be used to
4 supply the necessary potentials to the metal laminates of the lens.

5 Gas can be added for concurrent flow of gas from a concurrent gas source **200**
6 introduced through a concurrent gas inlet **202**. In ~~addition~~ addition, gas can be
7 added for a countercurrent flow from a countercurrent gas source **204** through a
8 countercurrent gas inlet **206**. Excess gas can be exhausted through an exhaust
9 outlet **210** toward an exhaust destination **208**. All gas supplies are regulated and
10 metered and of adequate purity to the meet the needs of the ion transmission
11 application.

12 **FIGS 5, 6, 7--ADDITIONAL EMBODIMENTS**

13 Additional embodiments of the lens are shown in Figs 5, 6, and 7. In Fig 5 the
14 cylindrical lens **140** is shown as two separate electrode, a cylindrical electrode **142**
15 and a shielding electrode **144** separated by a ring insulator **152**, and the shielding
16 electrode **144** separated from the outer-laminate **320** by the ring insulator **170**; in Fig
17 6 the outer-laminate **320** is shown as two separate elements, circular metal
18 laminates **322**, **344**, the circular metal laminate **322** populated with laminated
19 openings **360** and the laminate **344** isolated from the shielding electrode **144** by the
20 ring insulator **170**; in Fig 7A the inner-laminate **310** is fabricated with additional
21 electrodes, a ring electrode **352** and a funnel-focusing electrode **350**, which are
22 axial-symmetric with apertures **40**, **50**, **60** and the particle-stop **340**; in Fig 7B the
23 cylindrical-funnel wall **410** is isolated from the inner-laminate **310** by a ring insulator
24 **412** and isolated from the metal laminate **401** by a ring insulator **414**; and in Fig 7C a
25 ring electrode **354** is added to the ion-funnel region **400**.

26 **FIGS 8 THRU 11—ALTERNATIVE EMBODIMENTS**

27 There are various possibilities with regard to the make-up and geometry of the
28 laminates of the lens and laminated high-transmission elements (Lam-HTE).

29 Fig 8 shows a cross-sectional view of a lens composed of a cone-shaped array of
30 metal laminates adjacent to a high-transmission element (Lam-HTE) **300** with

1 ~~lamination on both sides.~~

2 Fig 9 shows a cross-sectional view of a lens composed of a hemispheric-shaped
3 array of metal laminates adjacent to a planar-shaped high-transmission element 300
4 comprised of a single electrode 320 and an insulating base 330 partially removed;
5 showing ion trajectories 162.

6 Fig 10 shows a cross-sectional view of a similar lens adjacent to a hemispherical-
7 shaped laminated high transmission element (Lam-HTE) 300.

8 Fig 11 shows a cross-sectional view of a lens downstream of an atmospheric
9 pressure matrix assisted laser desorption ionization (AP-MALDI) source including a
10 laser 124, a sample target 126, and an ion-source 120, without a high-transmission
11 lens sandwich between the two. The cylindrical electrode 140 separated from
12 cylindrical funnel wall 410 by a ring insulator 172.

13 **ADVANTAGES**

14 ~~From the description above, a number of advantages of our laminated lens~~
15 ~~become evident:~~

16 ~~(a) With the establishment of a low electrostatic field between the laminated high~~
17 ~~transmission surface and the laminated lens, one can shape the electrostatic field~~
18 ~~lines with a small potential apply to either the metallic layers of the laminated lens or~~
19 ~~the underside of the laminated high transmission surface, thus avoiding the need for~~
20 ~~larger potentials required in region where the electrostatic fields from high field ion~~
21 ~~sources dominate.~~

22 ~~(b) With the establishment of a low electrostatic field between the high~~
23 ~~transmission surface and the laminated lens, electrostatic fields lines can be focused~~
24 ~~onto a small cross-sectional area at the inlet aperture, thus avoiding the need for~~
25 ~~larger inlet apertures used to get ions into the vacuum system of a mass~~
26 ~~spectrometer.~~

27 ~~(c) The presence of a focusing element on the underside of the laminated high-~~
28 ~~transmission surface along with the individual laminates of the laminate lens will~~
29 ~~permit time dependent adjustment of the electrostatic fields in front of the inlet~~
30 ~~aperture.~~

(d) ~~The presence of a focusing element on the underside of the laminated high-transmission surface and the potentials of the individual laminates of the laminated lens will permit the time-dependent transmission of ions through the high-transmission surface [control ion flow through HTE].~~

OPERATION - FIGS 1 THRU 11

This device is intended for use in collection and focusing of ions from a wide variety of atmospheric or near atmospheric ion sources; including, but not limited to electrospray, atmospheric pressure chemical ionization, photo-ionization, electron ionization, laser ionization (including matrix assisted), inductively coupled plasma, discharge ionization. Both gas-phase ions and charged particles emanating from ion-source region **120** are collected, focused, and introduced into the vacuum system of a mass spectrometer.

Ions and charged particles supplied or generated in the ion-source region **160** are attracted to the outer-electrode surface **320** of the ~~laminated high-transmission element~~ Lam-HTE **300** by the DC electric potential difference between the ion-source **120** and the potential on outer-electrode surface **320**.

The ions moving toward the outer-electrode surface **320** and particle stop **340** are diverted away from the metal laminate surface through the laminated opening (as shown by generalized ion trajectories **162**) by the presence of the electric field penetrating through the base **330** from the inner-electrode surface **310** into the ion source region **160**. Making the ~~laminated high-transmission element~~ Lam-HTE transparent to approximately all ions moving from the ion source **120** into region **400**.

To move ions, that have passed through the ~~laminated high-transmission element~~ Lam-HTE into the ion-collection region **80**, lower DC electrical potentials are applied to the metal laminates **10** of the lens and the element **70** to cause ions to move into the larger aperture **40** and pass through the lens out through the smaller aperture **50**, through aperture **60** of element **70**, and into the ion-detection region **80**.

Gas flowing in a direction that is counter to the movement of ions will serve to reduce or eliminate contamination from particulate materials and neutral gases.

1 Operation with a counter-flow of gas is accomplished by adding a sufficient flow of
2 gas from the countercurrent gas source **204** flowing out through the ion funnel region
3 **400**, through the laminated openings **360** and into the ion-source region **160**, to
4 prevent contamination of the outer-surface **320** of the laminated high-transmission
5 element Lam-HTE 300. In addition, lower mobility charged particles may also be
6 swept away in the counter-flow of gas. Counter flow of gas is also a primary carrier
7 of enthalpy required for evaporation of droplets, both charged and uncharged.

8 Additional means of focusing ions can be used to focus ions into the lens by
9 fabricating the inner-laminate of the ~~high-transmission element~~ Lam-HTE 300 with
10 additional electrodes and by placing electrodes in the ion-funnel region **400**.

11 As shown in Fig Figs 7A thru 7C, additional electrodes with DC potentials different
12 from the DC potentials of the inner-electrode surface **310** and metal laminate **401**,
13 additional focusing can be imparted on the ions. By establishing the DC electrical
14 potential of the funnel-focusing element **350** at a lower potential than the potentials
15 of the inner-electrode **310** and metal laminate **410**, the field lines emanating out of
16 the ion-funnel will reach out further into the ion-funnel region **400** facilitating the
17 movement of ions from the ion-funnel region **400** into the largest aperture **40**.

18 Therefore, ions exiting the laminated openings can be focused down into the lens
19 avoiding possible collisions with the metal laminates **10**. Therefore, if the lens has
20 additional focusing in the ion-funnel region **400** substantially all of the ions passing
21 through the laminated high-transmission element **300** will be directed into the lens
22 and be introduced into the ion-detection region **80**.

23 The lens can be used to collect and focus ions from low-field sources, such as an
24 atmospheric matrix assisted laser desorption ionization (AP-MALDI) ion sources;
25 one simply configures the lens without a high-transmission element, either laminated
26 or not. As shown in Fig 11 when the lens is configured downstream of an AP-MALDI
27 source, ions desorbed from the sample target **126** form a plasma of charged
28 particles and matrix in the ion-source region **160**. The charged particles in region
29 **160** move toward the entrance aperture of the lens by means of establishing the DC
30 electrical potentials of the lens and element **70** at a lower potential than the sample
31 target **126** and walls **130**, **140**, **410**. Thereby eliminating the need for a high-
32 transmission element to shield the lens from the high fields of the ion source. In

1 addition, the laser target **126** and walls can all be at ground potential, eliminating the
2 need for costly interlocks to protect the analyst from high voltages.

3 Figs 8, and 9 and 10; show cone-shaped and hemispherical-shaped metal
4 laminates of the lens focusing ions ~~into and through aperture 60~~ into, through
5 aperture 60, and into ion-collection region **80**, respectively.

6 **ADVANTAGES**

7 From the description above, a number of advantages of our laminated lens
8 become evident:

9 (a) With the establishment of a low electrostatic field between the laminated high
10 transmission surface and the laminated lens, one can shape the electrostatic field
11 lines with a small potential apply to either the metallic layers of the laminated lens or
12 the underside of the laminated high-transmission surface, thus avoiding the need for
13 larger potentials required in region where the electrostatic fields from high field ion
14 sources dominate.

15 (b) With the establishment of a low electrostatic field between the high
16 transmission surface and the laminated lens, electrostatic fields lines can be focused
17 onto a small cross-sectional area at the inlet aperture, thus avoiding the need for
18 larger inlet apertures used to get ions into the vacuum system of a mass
19 spectrometer.

20 (c) The presence of a focusing element on the underside of the laminated high-
21 transmission surface along with the individual laminates of the laminate lens will
22 permit time-dependent adjustment of the electrostatic fields in front of the inlet
23 aperture.

24 (d) The presence of a focusing element on the underside of the laminated high-
25 transmission surface and the potentials of the individual laminates of the laminated
26 lens will permit the time-dependent transmission [or not] of ions through the high-
27 transmission surface.

28 **CONCLUSION, RAMIFICATION, AND SCOPE**

29 Accordingly, the reader will see that the laminated lens of this invention can be

1 used to introduce ions into the vacuum system of a mass spectrometer and can be
2 used with both high and low electrostatic field ion sources without considering the
3 electrostatic fields in the ion source. In addition, when a the laminate lens is used to
4 introduce ions into an inlet aperture the potentials of the laminates of the laminated
5 lens and high-transmission surface can be optimized to shape the electrostatic field
6 lines in front of the inlet aperture to be either converging or diverging. Furthermore,
7 the laminated lens has the additional advantages in that:

8 • it provides a laminated lens which can be easily incorporated into existing
9 high and low electrostatic field atmospheric or near atmospheric ion sources;

10 • it provides a laminated lens which can transfer substantially all gas phase
11 ions from dispersive ion sources into the vacuum system of a mass spectrometer;
12 and

13 • it provides a time dependent switching of the focusing and defocusing of the
14 ions as they pass through the high transmission surface into the low electrostatic
15 fields upstream of the laminated lens.

16 Although the description above contains many specifications, these should not be
17 construed as limiting the scope of the invention but as merely providing illustrations
18 of some of the presently preferred embodiments of this invention. For example the
19 laminated lens can have other shapes, such as oval, square, triangular, etc.;
20 laminated-openings can have other shapes; the number of laminates of the
21 laminated high-transmission element can vary depending on the preferred use; the
22 number and dimensions of both the metal laminates and insulating bases of the lens
23 can vary depending on the source of ions, the type of ion-collection region or a
24 combination of both, etc.

25 Thus the scope of the invention should be determined by the appended claims and
26 their legal equivalents, rather than by the examples given.